INTERNATIONAL STANDARD

ISO 10211

Second edition
2017-06

Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations

Ponts thermiques dans les bâtiments — Flux thermiques et températures superficielles — Calculs détaillés

Reference number
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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www. iso. org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www. iso. org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso. org/iso/foreword. html.

ISO 10211 was prepared by ISO Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 89, *Thermal performance of buildings and building components,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 10211:2007), which has been technically revised.

The changes in the second edition are mostly editorial. The standard has been re-drafted according to CEN/TS 16629:2014.

Introduction

This document is part of a series aimed at the international harmonization of the methodology for assessing the energy performance of buildings. Throughout, this series is referred to as a “set of EPB standards”.

All EPB standards follow specific rules to ensure overall consistency, unambiguity and transparency.

All EPB standards provide a certain flexibility with regard to the methods, the required input data and references to other EPB standards, by the introduction of a normative template in Annex A and Annex B with informative default choices.

For the correct use of this document, a normative template is given in Annex A to specify these choices. Informative default choices are provided in Annex B.

The main target groups for this document are architects, engineers and regulators.

Use by or for regulators: In case the document is used in the context of national or regional legal requirements, mandatory choices may be given at national or regional level for such specific applications. These choices (either the informative default choices from Annex B or choices adapted to national/regional needs, but in any case following the template of Annex A) can be made available as national annex or as separate (e.g. legal) document (national data sheet).

NOTE 1 So in this case:

— the regulators will specify the choices;

— the individual user will apply the document to assess the energy performance of a building, and thereby use the choices made by the regulators.

Topics addressed in this document can be subject to public regulation. Public regulation on the same topics can override the default values in Annex B. Public regulation on the same topics can even, for certain applications, override the use of this document. Legal requirements and choices are in general not published in standards but in legal documents. In order to avoid double publications and difficult updating of double documents, a national annex may refer to the legal texts where national choices have been made by public authorities. Different national annexes or national data sheets are possible, for different applications.

It is expected, if the default values, choices and references to other EPB standards in Annex B are not followed due to national regulations, policy or traditions, that:

— national or regional authorities prepare data sheets containing the choices and national or regional values, according to the model in Annex A. In this case a national annex (e.g. NA) is recommended, containing a reference to these data sheets;

— or, by default, the national standards body will consider the possibility to add or include a national annex in agreement with the template of Annex A, in accordance to the legal documents that give national or regional values and choices.

Further target groups are parties wanting to motivate their assumptions by classifying the building energy performance for a dedicated building stock.

More information is provided in the Technical Report accompanying this document (ISO/TR 52019-2).

The subset of EPB standards prepared under the responsibility of ISO/TC 163/SC 2 cover *inter alia*:

— calculation procedures on the overall energy use and energy performance of buildings;

— calculation procedures on the internal temperature in buildings (e.g. in case of no space heating or cooling);

— indicators for partial EPB requirements related to thermal energy balance and fabric features;

— calculation methods covering the performance and thermal, hygrothermal, solar and visual characteristics of specific parts of the building and specific building elements and components, such as opaque envelope elements, ground floor, windows and facades.

ISO/TC 163/SC 2 cooperates with other technical committees for the details on appliances, technical building systems, indoor environment, etc.

This document sets out the specifications for a geometrical model of a thermal bridge for the numerical calculation of linear thermal transmittances, point thermal transmittances and internal surface temperatures.

Table 1 shows the relative position of this document within the set of EPB standards in the context of the modular structure as set out in ISO 52000-1.

NOTE 2 In ISO/TR 52000-2 the same table can be found, with, for each module, the numbers of the relevant EPB standards and accompanying technical reports that are published or in preparation.

NOTE 3 The modules represent EPB standards, although one EPB standard could cover more than one module and one module could be covered by more than one EPB standard, for instance, a simplified and a detailed method respectively. See also Tables A.1 and B.1.

Table 1 — Position of this document (*in casu* M2–5) within the modular structure of the set of EPB standards

	Overarching		**Building (as such)**		**Technical Building Systems**									
Sub-module	**Descriptions**		**Descriptions**		**Descriptions**	**Heating**	**Cooling**	**Ventilation**	**Humidification**	**Dehumidification**	**Domestic hot water**	**Lighting**	**Building automation and control**	**PV, wind, ..**
sub1		**M1**		**M2**		**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
1	General		General		General									
2	Common terms and definitions; symbols, units and subscripts		Building energy needs		Needs								a	
3	Applications		(Free) indoor conditions without systems		Maximum load and power									
4	Ways to express energy performance		Ways to express energy performance		Ways to express energy performance									
5	Building categories and building boundaries		Heat transfer by transmission	ISO 10211	Emission and control									

a The shaded modules are not applicable.

Table 1 *(continued)*

	Overarching		Building (as such)		Technical Building Systems									
Sub-module	Descriptions		Descriptions		Descriptions	Heating	Cooling	Ventilation	Humidification	Dehumidification	Domestic hot water	Lighting	Building automation and control	PV, wind, ..
sub1		M1		M2		M3	M4	M5	M6	M7	M8	M9	M10	M11
6	Building occupancy and operating conditions		Heat transfer by infiltration and ventilation		Distribution and control									
7	Aggregation of energy services and energy carriers		Internal heat gains		Storage and control									
8	Building zoning		Solar heat gains		Generation and control									
9	Calculated energy performance		Building dynamics (thermal mass)		Load dispatching and operating conditions									
10	Measured energy performance		Measured energy performance		Measured Energy Performance									
11	Inspection		Inspection		Inspection									
12	Ways to express indoor comfort				BMS									
13	External environment conditions													
14	Economic calculation													

[a] The shaded modules are not applicable.

Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations

1 Scope

This document sets out the specifications for a three-dimensional and a two-dimensional geometrical model of a thermal bridge for the numerical calculation of

— heat flows, in order to assess the overall heat loss from a building or part of it, and

— minimum surface temperatures, in order to assess the risk of surface condensation.

These specifications include the geometrical boundaries and subdivisions of the model, the thermal boundary conditions, and the thermal values and relationships to be used.

This document is based upon the following assumptions:

— all physical properties are independent of temperature;

— there are no heat sources within the building element.

This document can also be used for the derivation of linear and point thermal transmittances and of surface temperature factors.

NOTE Table 1 in the Introduction shows the relative position of this document within the set of EPB standards in the context of the modular structure as set out in ISO 52000-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*

ISO 7345, *Thermal insulation — Physical quantities and definitions*

ISO 13370, *Thermal performance of buildings — Heat transfer via the ground — Calculation methods*

ISO 13788, *Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods*

ISO 10456, *Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values*

ISO 13789, *Thermal performance of buildings — Transmission and ventilation heat transfer coefficients — Calculation method*

ISO 52000-1:2017, *Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures*

NOTE 1 Default references to EPB standards other than ISO 52000-1 are identified by the EPB module code number and given in Annex A (normative template in Table A.1) and Annex B (informative default choice in Table B.1).

EXAMPLE EPB module code number: M5–5, or M5–5,1 (if module M5–5 is subdivided), or M5–5/1 (if reference to a specific clause of the standard covering M5–5).

NOTE 2 In this document, there are no choices in references to other EPB standards. The sentence and note above is kept to maintain uniformity between all EPB standards.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 52000-1, and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
thermal bridge
part of the building envelope where the otherwise uniform thermal resistance is significantly changed by full or partial penetration of the building envelope by materials with a different thermal conductivity, and/or a change in thickness of the fabric, and/or a difference between internal and external areas, such as occur at wall/floor/ceiling junctions

3.2
linear thermal bridge
thermal bridge (3.1) with a uniform cross-section along one of the three orthogonal axes

3.3
point thermal bridge
localized *thermal bridge* (3.1) whose influence can be represented by a *point thermal transmittance* (3.20)

3.4
three-dimensional geometrical model
3-D geometrical model
geometrical model, deduced from building plans, such that for each of the orthogonal axes, the cross-section perpendicular to that axis changes within the boundary of the model

Note 1 to entry: See Figure 1.

3.5
three-dimensional flanking element
3-D flanking element
part of a *3-D geometrical model* (3.4) which, when considered in isolation, can be represented by a *2-D geometrical model* (3.7)

Note 1 to entry: See Figure 1 and Figure 2.

3.6
three-dimensional central element
3-D central element
part of a *3-D geometrical model* (3.4) which is not a *3-D flanking element* (3.5)

Note 1 to entry: See Figure 1.

Note 2 to entry: A central element is represented by a *3-D geometrical model* (3.4).

3.7
two-dimensional geometrical model
2-D geometrical model
geometrical model, deduced from building plans, such that for one of the orthogonal axes, the cross-section perpendicular to that axis does not change within the boundaries of the model

Note 1 to entry: See Figure 2.

Note 2 to entry: A 2-D geometrical model is used for two-dimensional calculations.

3.8
two-dimensional flanking element
2-D flanking element
part of a *2-D geometrical model* (3.7) which, when considered in isolation, consists of plane, parallel material layers

Note 1 to entry: The plane, parallel material layers can be homogeneous or non-homogeneous.

3.9
two-dimensional central element
2-D central element
part of a *2-D geometrical model* (3.7) which is not a *2-D flanking element* (3.8)

3.10
construction plane
plane in the *3-D geometrical model* (3.4) or *2-D geometrical model* (3.7) which separates different materials, and/or the geometrical model from the remainder of the construction, and/or the flanking elements from the central element

Note 1 to entry: See Figure 3.

3.11
cut-off plane
construction plane (3.10) that is a boundary to the *3-D geometrical model* (3.4) or *2-D geometrical model* (3.7) by separating the model from the remainder of the construction

Note 1 to entry: See Figure 3.

3.12
auxiliary plane
plane which, in addition to the *construction planes* (3.10), divides the geometrical model into a number of cells

3.13
quasi-homogeneous layer
layer which consists of two or more materials with different thermal conductivities, but which can be considered as homogeneous with an equivalent thermal conductivity

Note 1 to entry: See Figure 4.

3.14
temperature factor at the internal surface
difference between internal surface temperature and external temperature, divided by the difference between internal temperature and external temperature, calculated with a surface resistance R_{si} at the internal surface

3.15
temperature weighting factor
weighting factor which states the respective influence of the temperatures of the different thermal environments upon the surface temperature at the point under consideration

3.16
external boundary temperature
external air temperature, assuming that the air temperature and the radiant temperature seen by the surface are equal

3.17
internal boundary temperature
operative temperature, taken as the arithmetic mean value of internal air temperature and mean radiant temperature of all surfaces surrounding the internal environment

3.18
thermal coupling coefficient
heat flow rate per temperature difference between two environments which are thermally connected by the construction under consideration

3.19
linear thermal transmittance
heat flow rate in the steady-state compared to a reference heat flow rate calculated disregarding the *thermal bridge* (3.1), divided by length and by the temperature difference between the environments on either side of a *linear thermal bridge* (3.2)

Note 1 to entry: The linear thermal transmittance is a quantity describing the influence of a linear thermal bridge on the total heat flow.

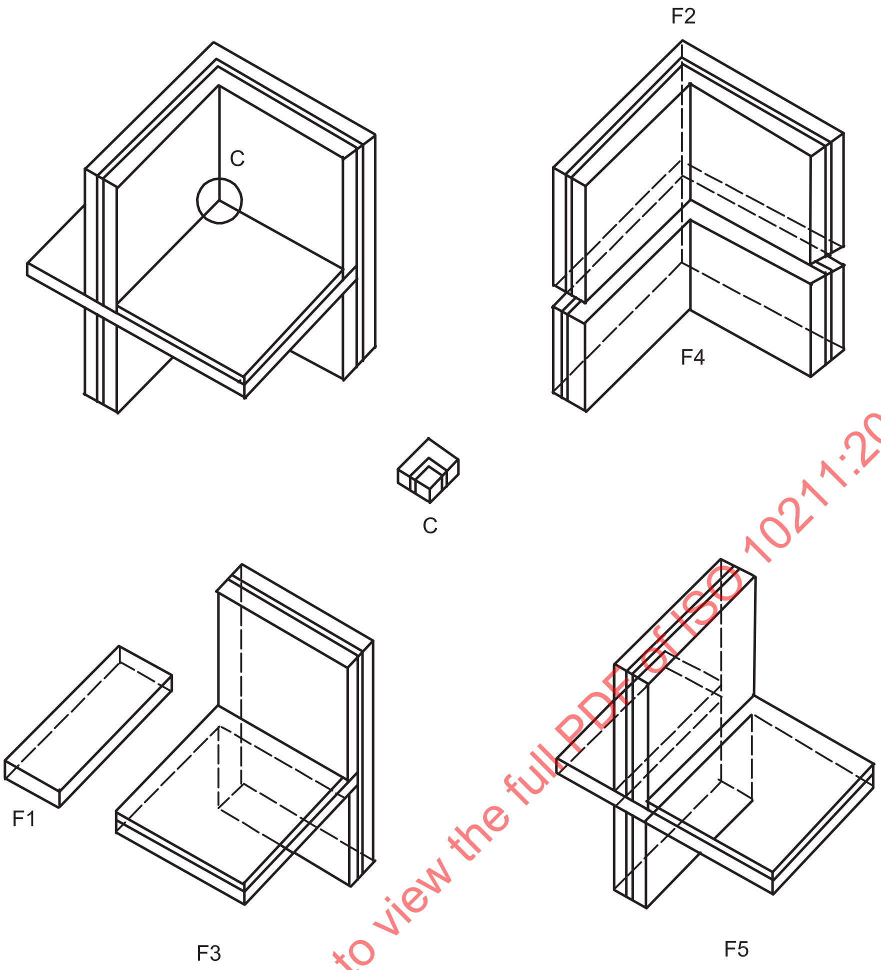
3.20
point thermal transmittance
heat flow rate in the steady-state compared to a reference heat flow rate calculated disregarding the *thermal bridge* (3.1), divided by the temperature difference between the environments on either side of a *point thermal bridge* (3.3)

Note 1 to entry: The point thermal transmittance is a quantity describing the influence of a point thermal bridge on the total heat flow.

3.21
EPB standard
standard that complies with the requirements given in ISO 52000-1, CEN/TS 16628[5] and CEN/TS 16629[6]

Note 1 to entry: These three basic EPB documents were developed under a mandate given to CEN by the European Commission and the European Free Trade Association and support essential requirements of EU Directive 2010/31/EU on the energy performance of buildings. Several EPB standards and related documents are developed or revised under the same mandate.

[SOURCE: ISO 52000-1:2017, 3.5.14]



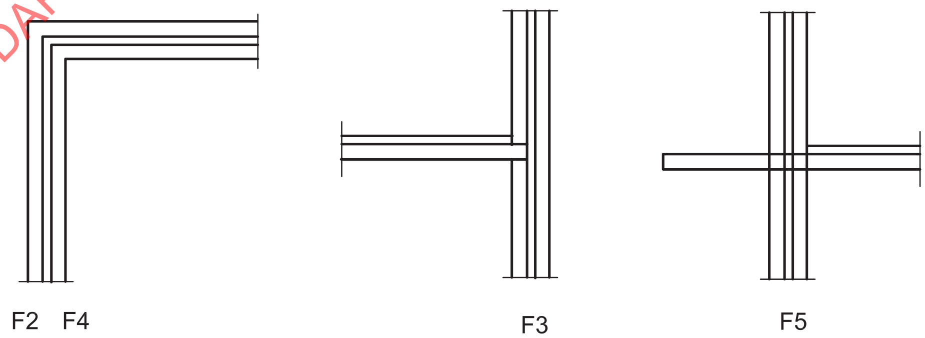
Key

F1, F2, F3, F4, F5 3-D flanking elements

C 3-D central element

NOTE 3-D Flanking elements have constant cross-sections perpendicular to at least one axis; the 3-D central element is the remaining part.

Figure 1 — 3-D geometrical model with five 3-D flanking elements and one 3-D central element

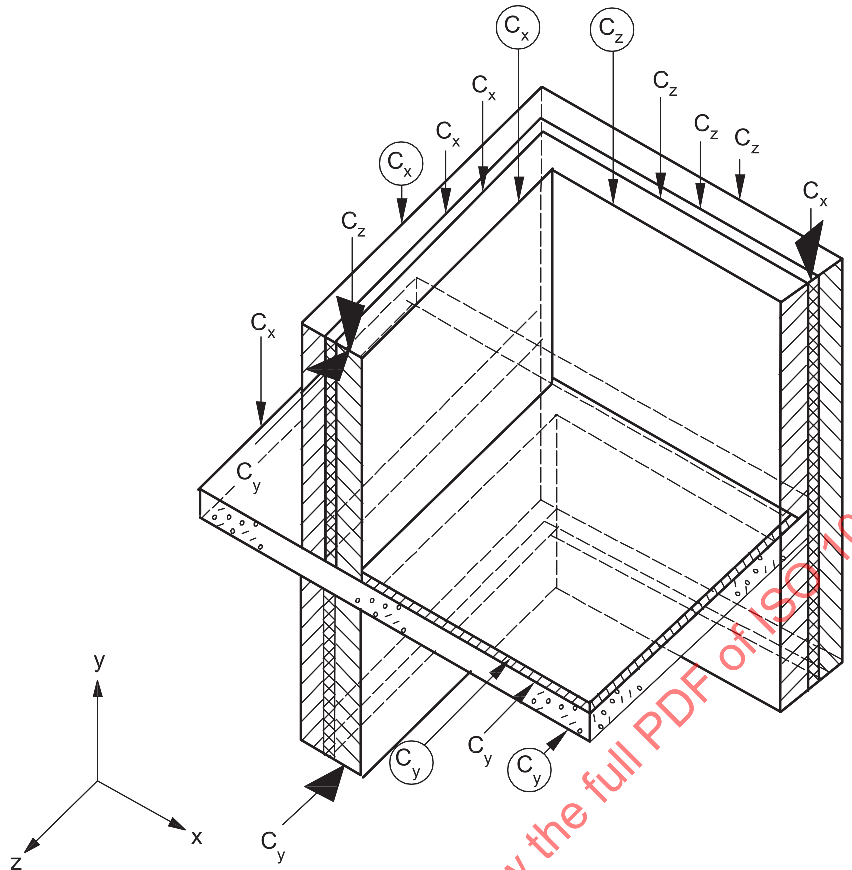


Key

F1, F2, F3, F4, F5 3-D flanking elements

NOTE F2 to F5 refer to Figure 1.

Figure 2 — Cross-sections of the 3-D flanking elements in a 3-D geometrical model treated as 2-D geometrical models



Key

C_x construction planes perpendicular to the x-axis

C_y construction planes perpendicular to the y-axis

C_z construction planes perpendicular to the z-axis

NOTE Cut-off planes are indicated with enlarged arrows; planes that separate flanking elements from central element are encircled.

Figure 3 — Example of a 3-D geometrical model showing construction planes

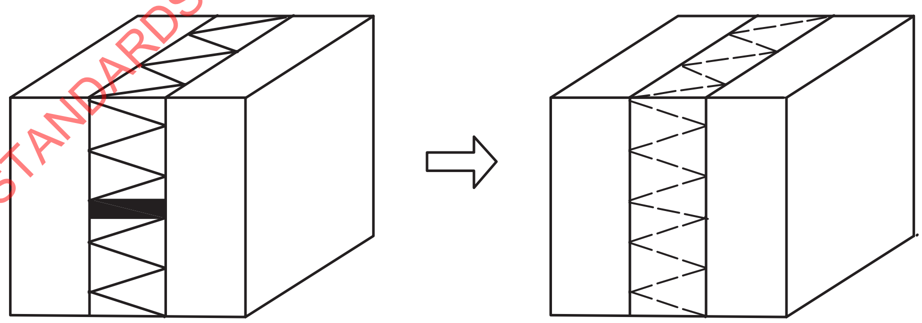


Figure 4 — Example of a minor point thermal bridge giving rise to three-dimensional heat flow, incorporated into a quasi-homogeneous layer

4 Symbols and subscripts

4.1 Symbols

For the purposes of this document, the symbols given in ISO 52000-1 and the following apply.

Symbol	Quantity	Unit
A	area	m^2
B	characteristic dimension of floor	m
b	width	m
d	thickness	m
f	temperature factor at the internal surface	—
g	temperature weighting factor	—
h	height	m
L	thermal coupling coefficient	W/(m·K)
L_{2D}	thermal coupling coefficient from two-dimensional calculation	W/(m·K)
L_{3D}	thermal coupling coefficient from three-dimensional calculation	W/K
l	length	m
N	number	—
q	density of heat flow rate	W/m^2
R	thermal resistance	$m^2 \cdot K/W$
T	thermodynamic temperature	K
t	time	month
U	thermal transmittance	$W/(m^2 \cdot K)$
V	volume	m^3
w	wall thickness	m
z	depth of floor surface below ground level	m
Φ	heat flow rate	W
λ	thermal conductivity	W/(m·K)
θ	Celsius temperature	°C
$\Delta\theta$	temperature difference	K
χ	point thermal transmittance	W/K
Ψ	linear thermal transmittance	W/(m·K)

4.2 Subscripts

For the purposes of this document, the subscripts given in ISO 52000-1 and the following apply.

Subscript	Definition
b	basement, below ground level
c	component
e	external
f	floor
g	air layer, air gap (8.6)
g	ground (12.4)
ie	from internal to external
iu	from internal to unheated
int	internal

Subscript	Definition
min	minimum
pe	external periodic heat transfer coefficient
se	external surface
si	internal surface
t	including thermal bridge (total)
tb	thermal bridge
ue	from unheated to external
w	wall
0	without thermal bridge

5 Description of the method

5.1 Output

The output of this document is the linear thermal transmittances, point thermal transmittances and internal surface temperatures. The formulae for doing so are provided in Clause 10 to Clause 13.

5.2 General description

The temperature distribution within, and the heat flow through, a construction can be calculated if the boundary conditions and constructional details are known. For this purpose, the geometrical model is divided into a number of adjacent material cells, each with a homogeneous thermal conductivity. The criteria which shall be met when constructing the model are given in Clause 7.

In Clause 8, instructions are given for the determination of the values of thermal conductivity and boundary conditions.

The temperature distribution is determined either by means of an iterative calculation or by a direct solution technique, after which the temperature distribution within the material cells is determined by interpolation. The calculation rules and the method of determining the temperature distribution are described in Clause 9.

NOTE Specific procedures for window frames are given in ISO 10077-2.

6 Output data and input data

6.1 Output data

The output data are listed in Table 2.

Table 2 — Output data

Description	Symbol	Unit	Destination module (Table 1)	Validity interval	Varying
linear thermal transmittance	Ψ	W/(m·K)	M2-5	—	No
thermal coupling coefficient from two-dimensional calculation	L_{2D}	W/(m·K)	M2-5	>0	No
thermal coupling coefficient from three-dimensional calculation	L_{3D}	W/K	M2-5	>0	No
temperature factor at the internal surface	f_{Rsi}	—	M2-5	>0	No
point thermal transmittance	χ	W/K	M2-5	>0	No

6.2 Calculation time intervals

In most cases, the calculations described in this document are steady-state and do not have time intervals.

Where calculations are being undertaken to obtain periodic heat transfer coefficients (see 7.2.5), the time interval shall be 1 h or less.

6.3 Input data

Tables 3 and 4 list identifiers for input data required for the calculation.

Table 3 — Identifiers for geometric characteristics

Name	Symbol	Unit	Value	Range	Origin	Varying
Area	A	m^2	—	>0	—	No
Width of building component	b	m	—	>0	—	No
Thickness of building component	d	m	—	>0	—	No
Length	l	m	—	>0	—	No
Volume	V	m^3	—	>0	—	No
Characteristic dimension of floor	B	m	—	>0	ISO 13370	No

Table 4 — Identifiers for thermal characteristics of building component

Name	Symbol	Unit	Value	Range	Origin	Varying
design thermal conductivity	λ	W/(m·K)	—	0 to 200	ISO 10456	No
thermal resistance	R	m^2·K/W	—	>0	ISO 6946	No
external surface resistance	R_{se}	m^2·K/W	0,04	—	ISO 6946	No
internal surface resistance	R_{si}	m^2·K/W	—	0,1 to 0,2	ISO 6946	No
thermal transmittance	U	W/(m^2·K)	—	>0	ISO 6946	No
temperature	θ	°C	—	−50 to +50	—	No

7 Modelling of the construction

7.1 Dimension systems

Lengths are measured using internal dimensions, overall internal dimensions or external dimensions, according to the dimension system being used for the building (see ISO 13789).

7.2 Rules for modelling

7.2.1 General

It is not usually feasible to model a complete building using a single geometrical model. In most cases, the building is partitioned into several parts (including the subsoil, where appropriate) by using cut-off planes. This partitioning shall be performed in such a way that all differences are avoided in the results of calculation between the partitioned building and the building when treated as a whole. This partitioning into several geometrical models is achieved by choosing suitable cut-off planes.

7.2.2 Cut-off planes for a 3-D geometrical model for calculation of total heat flow and/or surface temperatures

The geometrical model includes the central element(s), the flanking elements and, where appropriate, the subsoil. The geometrical model is delimited by cut-off planes.

Cut-off planes shall be positioned as follows:

— at a symmetry plane if this is less than d_{min} from the central element (see Figure 5);

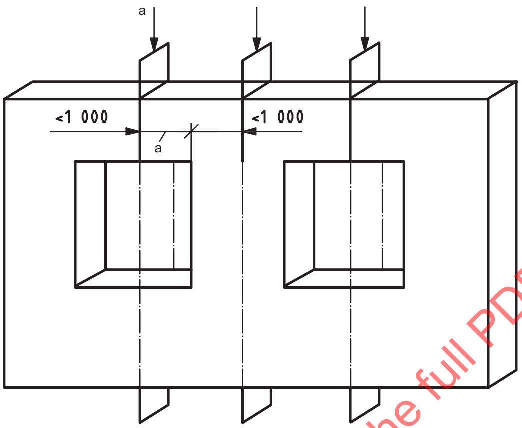
— at least d_{min} from the central element if there is no nearer symmetry plane (see Figure 6);

— in the ground, in accordance with 7.2.4

where d_{min} is the greater of 1 m and three times the thickness of the flanking element concerned.

A geometrical model can contain more than one thermal bridge. In such cases, cut-off planes need to be situated at least d_{min} from each thermal bridge, or need to be at a symmetry plane (see Figure 6).

Dimensions in millimetres

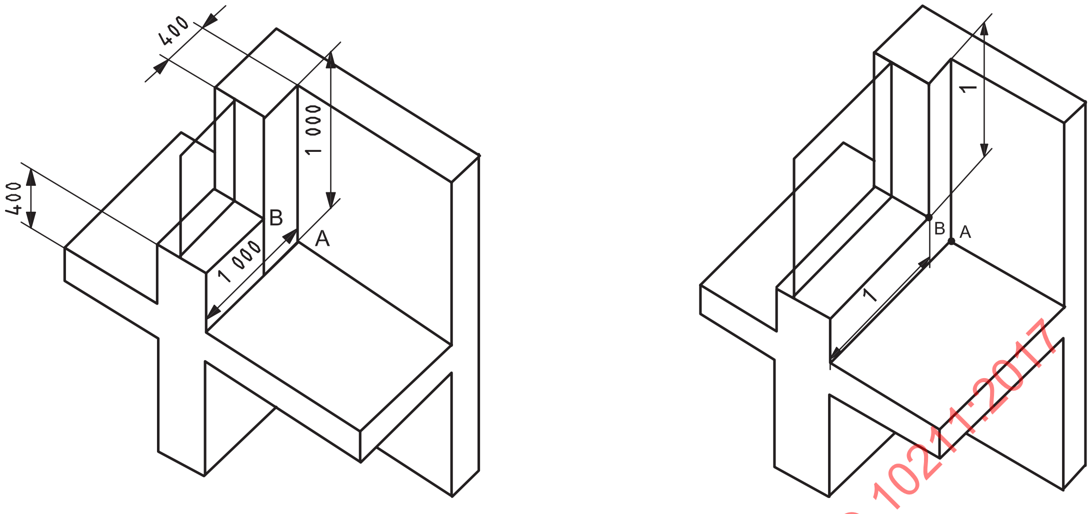


Key

a Arrows indicate the symmetry planes.

Figure 5 — Symmetry planes which can be used as cut-off planes

Dimensions in millimetres



a) b)

Key

1 1 000 mm or at a symmetry plane

A thermal bridge at the corner of the internal room

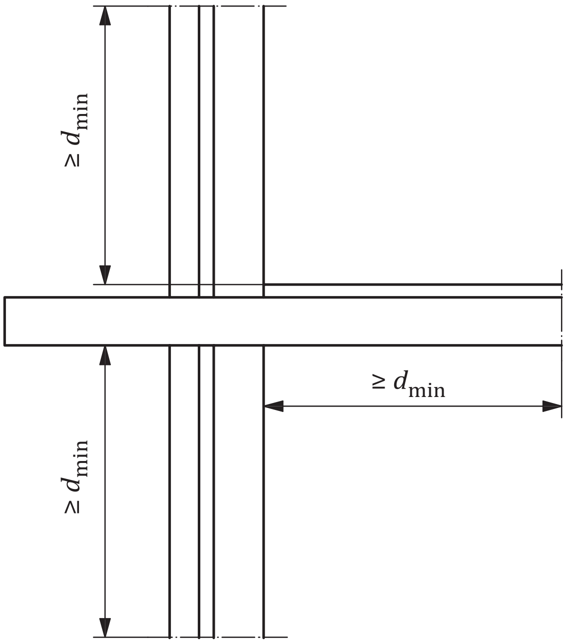
B thermal bridge around the window in the external wall

NOTE Thermal bridge B does not fulfil the condition of being at least d_{min} (= 1 m) from a cut-off plane [Figure 6 a)]. This is corrected by extending the model in two directions [Figure 6 b)].

Figure 6 — 3-D geometrical model containing two thermal bridges

7.2.3 Cut-off planes for a 2-D geometrical model

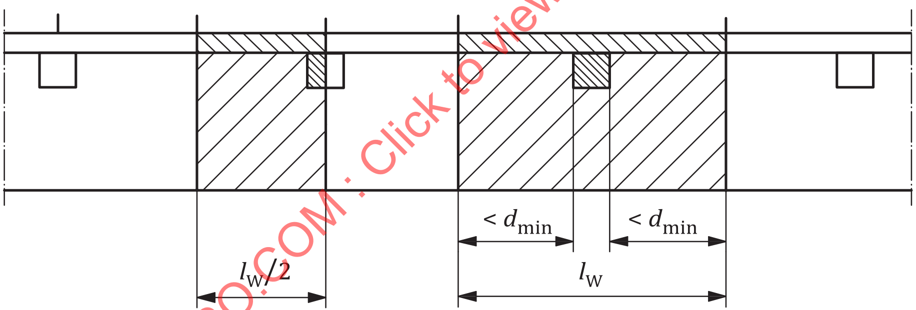
The same rules as given in 7.2.2 apply to a 2-D geometrical model. Examples are shown in Figure 7 and Figure 8. In Figure 8, the left-hand drawing may be used if the thermal bridge is symmetrical.



Key

d_{min} minimum thickness

Figure 7 — Location of cut-off planes at least d_{min} from the central element in a 2-D geometrical model



Key

d_{min} minimum thickness

l_W fixed distance

Figure 8 — Example of a construction with linear thermal bridges at fixed distances, l_W, showing symmetry planes which can be used as cut-off planes

7.2.4 Cut-off planes in the ground

Where the calculation involves heat transfer via the ground (foundations, ground floors, basements), the cut-off planes in the ground shall be positioned as indicated in Table 5. This includes ground below the internal walls in contact with ground.

Table 5 — Location of cut-off planes in the ground

Direction	Distance to central element	
	Purpose of the calculation	
	Surface temperatures only	Heat flow and surface temperatures[a]
Horizontal distance to vertical plane, inside the building	at least three times wall thickness	0,5 × floor dimension[b]
Horizontal distance to vertical plane, outside the building	at least three times wall thickness	2,5 × floor width[c,d]
Vertical distance to horizontal plane below ground level	at least 3 m	2,5 × floor width[c]
Vertical distance to horizontal plane below floor level (applies only if the level of the floor under consideration is more than 2 m below the ground level)	at least 1 m	2,5 × floor width[c]

[a] See Figure 9 and Figure 10.

[b] In a 3-D geometrical model, the floor dimensions (length and width) inside the building are to be considered separately in each direction (see Figure 9).

[c] In a 3-D geometrical model, the distance outside the building and below ground is to be based on the smaller dimension (width) of the floor (see Figure 9).

[d] If vertical symmetry planes are known, for example, as a result of adjacent buildings, they can be used as cut-off planes.

For two-dimensional calculations, there is a vertical symmetry plane in the middle of the floor (so that one half of the building is modelled). For three-dimensional calculations on a rectangular building, vertical adiabatic boundaries are taken in the ground mid-way across the floor in each direction (so that one quarter of the building is modelled). For non-rectangular buildings, it is necessary either to model the complete building (together with the ground on all sides), or to convert the problem to a two-dimensional one using a building of infinite length and of width equal to the characteristic dimension of the floor, B (see ISO 13370).

EXAMPLE For the floor illustrated in Figure 9, $B = b \cdot c/(b + c)$.

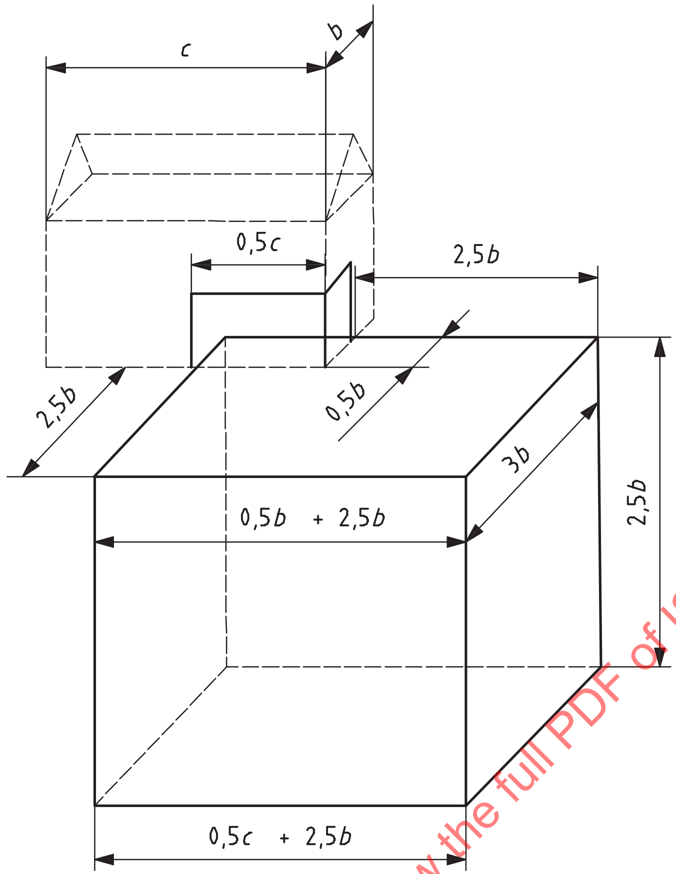
All cut-off planes shall be adiabatic boundaries.

7.2.5 Periodic heat flows via the ground

Similar criteria to those in 7.2.4 apply to time-dependent numerical calculations for the determination of periodic heat transfer coefficients (as defined in ISO 13370), except that adiabatic cut-off planes may be taken at positions equal to twice the periodic penetration depth measured from the edge of the floor in any direction (if these dimensions are less than those specified in 7.2.4). For further details, see 12.4.3.2.

7.2.6 Adjustments to dimensions

Adjustments to the dimensions of the geometrical model with respect to the actual geometry are allowed if the conditions in 7.3.2 are satisfied.

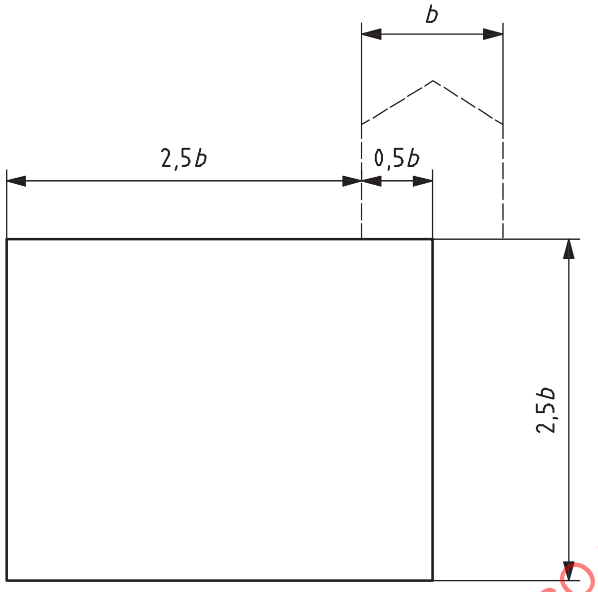


Key

b, *c* dimensions of floor

NOTE The floor dimensions are *b* · *c*, with *c* > *b*

Figure 9 — Cut-off planes for 3-D geometrical model which includes the ground



Key

b width of floor

Figure 10 — Cut-off planes for 2-D geometrical model which includes the ground

7.2.7 Auxiliary planes

The number of auxiliary planes in the model shall be such that at least one of the following criteria is met:

— doubling the number of subdivisions does not change the calculated heat flow through by more than 1 %;

— doubling the number of subdivisions does not change the temperature factor at the inside surface, f_{Rsi}, by more than 0,005.

NOTE 1 Requirements for validation of calculation methods are given in C.2.

NOTE 2 A satisfactory sub-division of the geometrical model will usually be obtained by arranging for the sub-divisions to be smallest within any central element, and gradually increasing in size to larger sub-divisions near cut-off planes.

7.2.8 Quasi-homogeneous layers and materials

In a geometrical model, materials with different thermal conductivities may be replaced by a material with a single thermal conductivity if the conditions in 7.3.3 are satisfied.

EXAMPLE Joints in masonry, wall-ties in thermally insulated cavities, screws in wooden laths, roof tiles and the associated air cavity and tile battens.

7.3 Conditions for simplifying the geometrical model

7.3.1 General

Calculation results obtained from a geometrical model with no simplifications shall have precedence over those obtained from a geometrical model with simplifications.

NOTE This is important when the results of a calculation are close to any required value.

The adjustments described in 7.3.2 can be made.

A template for further restrictions on simplification of the geometrical model is given in Table A.2, with an informative default choice in Table B.2.

7.3.2 Conditions for adjusting dimensions to simplify the geometrical model

Adjustment to the dimensions as described below may be made only to materials with thermal conductivity less than 3 W/(m·K).

a) Change in the location of the surface of a block of material adjacent to the internal or external surface of the geometrical model (see Figure 11): for the location of surfaces which are not flat, the local adjustment perpendicular to the mean location of the internal or external surface, d_c, shall not exceed as given in Formula (1):

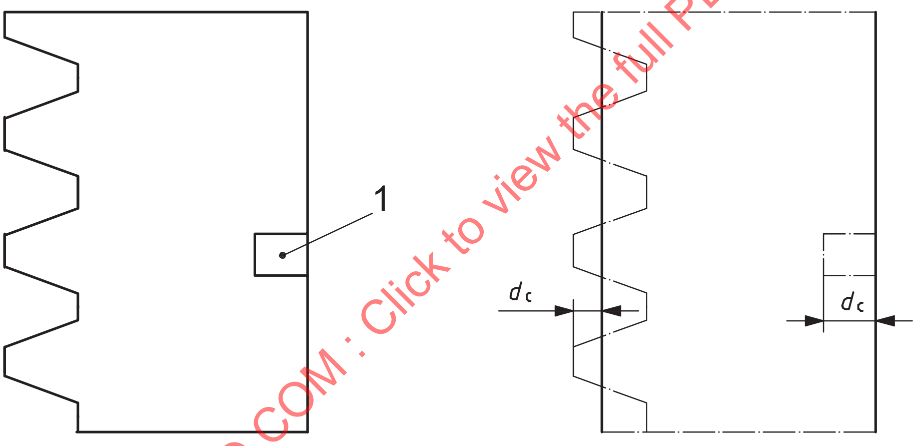
$$d_c = R_c \cdot \lambda \quad (1)$$

where

R_c is equal to 0,03 m^2·K/W;

λ is the thermal conductivity of the material in question.

EXAMPLE Inclined surfaces, rounded edges and profiled surfaces such as roof tiles.



Key

1 wall socket

d_c local adjustment perpendicular to the mean location of the internal or external surface

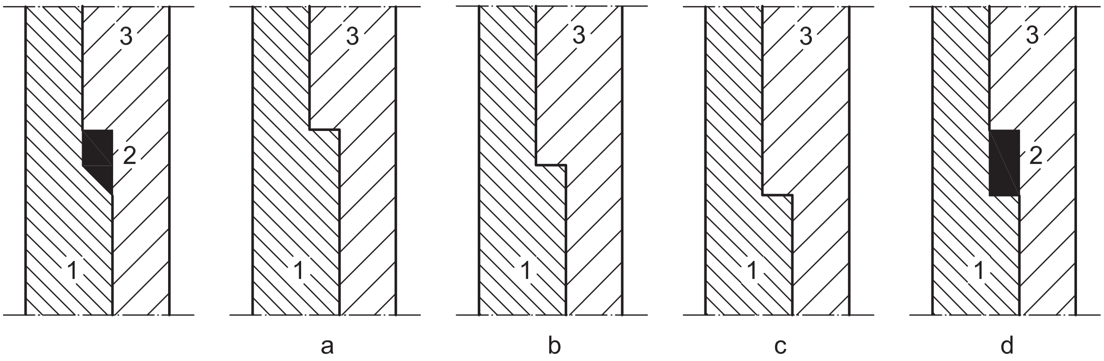
Figure 11 — Change in the location of the internal or external surface

b) Change in the interface of two regions of different material:

— the relocation of the interface shall take place in a direction perpendicular to the internal surface;

— the relocation of the interface shall be such that the material with the lower thermal conductivity is replaced by the material with the higher thermal conductivity (see Figure 12).

EXAMPLE Recesses for sealing strips, kit joints, adjusting blocks, wall sockets, inclined surfaces and other connecting details.



Combination		Simplifications			
Material block	Thermal conductivity	a	b	c	d
1	λ_1	$\lambda_1 > \lambda_2$	$\lambda_1 > \lambda_3$	$\lambda_1 < \lambda_3$	$\lambda_1 < \lambda_2$
2	λ_2				
3	λ_3		$\lambda_3 > \lambda_2$	$\lambda_3 > \lambda_2$	$\lambda_3 < \lambda_2$

Figure 12 — Four possibilities for relocating the interface between three material blocks, depending on the ratio of their thermal conductivities, λ

c) Neglecting thin layers:

— non-metallic layers with a thickness of not more than 1 mm may be ignored;

— thin metallic layers may be ignored if it is established that they have a negligible effect on the heat transfer.

EXAMPLE Thin membranes which resist the passage of moisture, water vapour or wind-driven air.

d) Neglecting appendages attached to the outside surface: components of the building which have been attached to the outside surface (i.e. attached at discrete points) may be neglected.

EXAMPLE Rainwater gutters and discharge pipes.

7.3.3 Conditions for using quasi-homogeneous material layers to simplify the geometrical model

7.3.3.1 All calculations

The following conditions for incorporating minor linear and point thermal bridges into a quasi-homogeneous layer apply in all cases:

— the layers of material in question are located in a part of the construction which, after simplification, becomes a flanking element;

— the thermal conductivity of the quasi-homogeneous layer after simplification is not more than 1,5 times the lowest thermal conductivity of the materials present in the layer before simplification.

7.3.3.2 Calculations performed to obtain the thermal coupling coefficient L_{3D} or L_{2D}

The equivalent thermal conductivity of the quasi-homogeneous layer, λ', shall be calculated in accordance with Formula (2) or Formula (3):

$$\lambda' = \frac{d}{\dfrac{A}{L_{3D}} - R_{si} - R_{se} - \sum \dfrac{d_j}{\lambda_j}} \qquad (2)$$

$$\lambda' = \frac{d}{\frac{l_{tb}}{L_{2D}} - R_{si} - R_{se} - \sum \frac{d_j}{\lambda_j}} \quad (3)$$

where

d is the thickness of the thermally inhomogeneous layer;

A is the area of the building component;

l_{tb} is the length of a linear thermal bridge;

L_{3D} is the thermal coupling coefficient of the building component determined by a 3-D calculation;

L_{2D} is the thermal coupling coefficient of the building component determined by a 2-D calculation;

d_j is the thickness of any homogeneous layer which is part of the building element;

λ_j are the thermal conductivities of these homogeneous layers.

NOTE The use of Formula (2) or Formula (3) is appropriate if a number of identical minor thermal bridges are present (wall-ties, joints in masonry, hollow blocks, etc.). The calculation of the thermal coupling coefficient can be restricted to a basic area that is representative of the inhomogeneous layer. For instance, a cavity wall with four wall-ties per square metre can be represented by a basic area of 0,25 m^2 with one wall-tie.

7.3.3.3 Calculations performed to obtain the internal surface temperature or the linear thermal transmittance, Ψ, or the point thermal transmittance, χ

See Clause 11 for calculations using linear and point thermal transmittances from 3-D calculations.

The equivalent thermal conductivity of the quasi-homogeneous layer, λ', may be taken as given in Formula (4):

$$\lambda' = \frac{\left(A_1 \cdot \lambda_1 + ... + A_n \cdot \lambda_n\right)}{\left(A_1 + ... + A_n\right)} \quad (4)$$

where

λ_1, ... λ_n are the thermal conductivities of the constituent materials;

A_1 ..... A_n are the areas of the constituent materials measured in the plane of the layer, provided that

— the thermal bridges in the layer under consideration are at, or nearly at, right angles to the internal or external surface of the building element and penetrate the layer over its entire thickness;

— the thermal resistance (surface to surface) of the building element after simplification is at least 1,5 (m^{-1} 2·K)/W;

— the conditions of at least one of the groups stated in Table 6 are met (see Figure 13).

Table 6 — Specific conditions for incorporating linear or point thermal bridges into a quasi-homogeneous layer

Group[a]	λ_{tb}[b] W/(m·K)	A_{tb}[c] m^2	R_0[e] m^2·K/W	$R_{t;i}$[f] m^2·K/W	λ_i[g] W/(m·K)	d_i[h] m
1	≤1,5	≤0,05 × l_{tb}[d]	≤0,5	—	—	—
2	>3	≤30 × 10^{-6}	≤0,5	—	—	—
3	>3	≤30 × 10^{-6}	>0,5	≥0,5	—	—
4	>3	≤30 × 10^{-6}	>0,5	<0,5	≥0,5	≥0,1

NOTE 1 Group 1 includes linear thermal bridges. Examples are joints in masonry, wooden battens in air cavities or in insulated cavities of minor thickness.

NOTE 2 Group 2 includes such items as wall-ties, insofar as they are fitted in masonry or concrete or are located in an air cavity, as well as nails and screws in layers of material or strips with the indicated maximum thermal resistance.

NOTE 3 Groups 3 and 4 include such items as cavity ties, insofar as they penetrate an insulation layer which has a higher thermal resistance than indicated for group 2. The inner leaf therefore needs to have thermal properties that limit the influence of the thermal bridge on the internal surface temperature, e.g. if the inner leaf has a sufficient thermal resistance (group 3) or the thermal conductivity of the inner leaf is such that the heat flow through the cavity ties is adequately distributed over the internal surface; most masonry or concrete inner leaves are examples of group 4.

a See Figure 12.

b λ_{tb} is the thermal conductivity of the thermal bridge to be incorporated into the quasi-homogeneous layer.

c A_{tb} is the area of the cross-section of the thermal bridge.

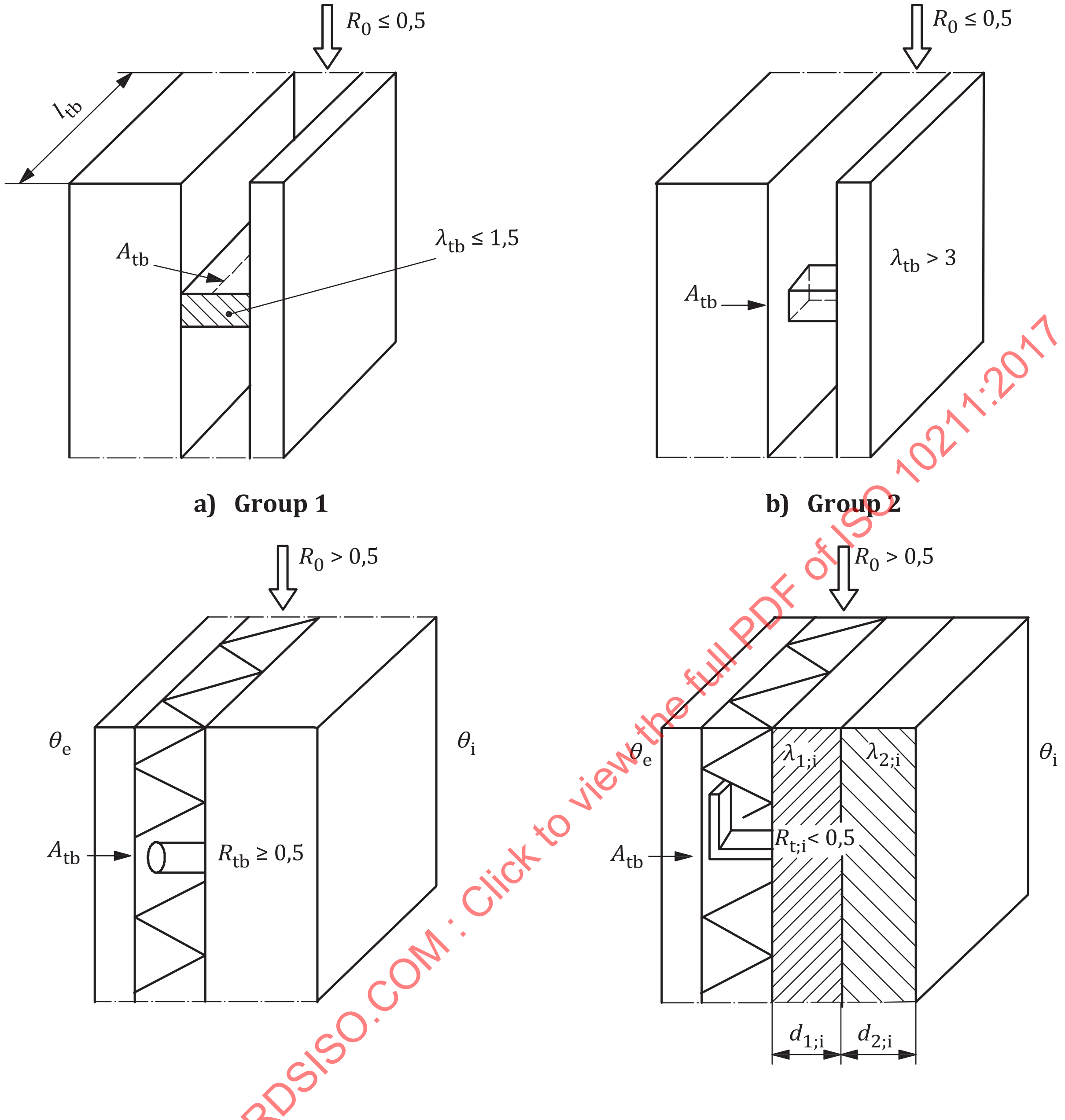
d l_{tb} is the length of a linear thermal bridge.

e R_0 is the thermal resistance of the layer without the presence of the point thermal bridge.

f $R_{t;i}$ is the total thermal resistance of the layers between the quasi-homogeneous layer considered and the internal surface.

g λ_i is the thermal conductivity of the material layer between the quasi-homogeneous layer considered and the internal surface with the highest value of λ_i d_i.

h d_i is the thickness of the same layer.



c) Group 3 d) Group 4

NOTE For key to symbols and subscripts, see Clause 4.

Figure 13 — Specific conditions for incorporating linear and point thermal bridges in a quasi-homogeneous layer for groups given in Table 6

8 Input data specifications

8.1 General

Use values as described in this clause unless non-standard values are justified for a particular situation.

NOTE Non-standard values can be justified by local conditions (i.e. established temperature distributions in the ground) or by specific material properties (i.e. the effect of a low emissivity coating on the surface resistance).

8.2 Thermal conductivities of materials

Values of design thermal conductivity shall be calculated in accordance with ISO 10456 if based on measured data supplied by the manufacturer.

In other cases, thermal conductivity is obtained from tabulated values. A template for the tabulated default values is given in Table A.3, with an informative default list in Table B.3.

The thermal conductivity of soil shall be as 2,0 W/(m·K) unless other values(s) are given in Table A.3.

8.3 Surface resistances

For the calculation of heat flow rates, surface resistances shall be in accordance with ISO 6946, depending on the direction of heat flow. However, the value of R_{si} corresponding to horizontal heat flow may be used for all surfaces when

— the direction of heat flow is uncertain or is liable to vary, or

— a whole building is being modelled in a single calculation.

For the calculation of internal surface temperatures for the purposes of evaluating condensation risk, surface resistances shall be in accordance with ISO 13788.

8.4 Boundary temperatures

Table 7 gives the boundary temperatures which shall be used.

Table 7 — Boundary temperatures

Location	Boundary temperature
Internal	Internal boundary temperature
Internal in unheated rooms	See 8.7
External	External boundary temperature
Soil (horizontal cut-off plane)	At the distance below ground level given in Table 5: adiabatic boundary condition

8.5 Thermal conductivity of quasi-homogeneous layers

The thermal conductivity of quasi-homogeneous layers shall be calculated in accordance with Formula (2), Formula (3) and Formula (4).

8.6 Equivalent thermal conductivity of air cavities

An air cavity shall be considered as a homogeneous conductive material with a thermal conductivity, λ_g.

If the thermal resistance of an air layer or cavity is known, its equivalent thermal conductivity, λ_g, is obtained from Formula (5):

$$\lambda_g = \frac{d_g}{R_g} \qquad (5)$$

where

d_g is the thickness of the air layer;

R_g is the thermal resistance in the main direction of heat flow.

Thermal resistances of air layers and cavities bounded by opaque materials shall be obtained by the procedure in ISO 6946.

For the thermal resistance of air layers in multiple glazing, see EN 673. Information about the treatment of cavities in window frames is given in ISO 10077-2.

Air cavities with dimensions of more than 0,5 m along each one of the orthogonal axis shall be treated as rooms (see 8.7).

8.7 Determining the temperature in an adjacent unheated room

If sufficient information is available, the temperature in an adjacent unheated room shall be calculated in accordance with ISO 13789.

If the temperature in an adjacent unheated room is unknown and cannot be calculated in accordance with ISO 13789 because the necessary information is not available, the heat flows and internal surface temperatures cannot be calculated. However, all required coupling coefficients and temperature weighting factors can be calculated and presented in accordance with Annex E.

9 Calculation method

9.1 Solution technique

The geometrical model is divided into a number of cells, each with a characteristic point (called a node). By applying the laws of energy conservation (div q = 0) and Fourier ($q = -\lambda$ grad θ) and taking into account the boundary conditions, a system of equations is obtained which is a function of the temperatures at the nodes. The solution of this system, either by a direct solution technique or by an iterative method, provides the node temperatures from which the temperature field can be determined. From the temperature distribution, the heat flows can be calculated by applying Fourier's law.

Calculation methods shall be verified in accordance with the requirements of Annex C.

9.2 Calculation rules

9.2.1 Heat flows between material cells and adjacent environment

The density of heat flow rate, q, perpendicular to the interface between a material cell and the adjacent environment shall satisfy Formula (6):

$$q = \frac{\left(\theta - \theta_s\right)}{R_s} \tag{6}$$

where

θ is the internal or external reference temperature;

θ_s is the temperature at the internal or external surface;

R_s is the internal or external surface resistance.

9.2.2 Heat flows at cut-off planes

The cut-off planes shall be adiabatic (i.e. zero heat flow).

9.2.3 Solution of the formulae

The formulae shall be solved in accordance with the requirements given in C.2.

9.2.4 Calculation of the temperature distribution

The temperature distribution within each material cell shall be calculated by interpolation between the node temperatures.

NOTE Linear interpolation suffices.

10 Determination of thermal coupling coefficients and heat flow rate from 3-D calculations

10.1 Two boundary temperatures, unpartitioned model

If there are only two environments with two different temperatures (e.g. one internal and one external temperature), and if the total room or building is calculated three-dimensionally from a single model, then the total thermal coupling coefficient, $L_{3D1,2}$, is obtained from the total heat flow rate, Φ, of the room or building, as given in Formula (7):

$$\Phi = L_{3D,1,2} \cdot \left(\theta_1 - \theta_2\right) \tag{7}$$

10.2 Two boundary temperatures, partitioned model

If the room or building has been partitioned (see Figure 14), the total $L_{3D,i,j}$ value is calculated from Formula (8):

$$L_{3D,i,j} = \sum_{k=1}^{N_k} U_{k(i,j)} \cdot A_k + \sum_{m=1}^{N_m} L_{2D,m(i,j)} \cdot l_m + \sum_{n=1}^{N_n} L_{3D,n(i,j)} \tag{8}$$

where

$L_{3D,n(i,j)}$	is the thermal coupling coefficient obtained from a 3-D calculation for part n of the room or building;
$L_{2D,m(i,j)}$	is the thermal coupling coefficient obtained from a 2-D calculation for part m of the room or building;
l_m	is the length over which the value $L_{2D,m(i,j)}$ applies;
$U_{k(i,j)}$	is the thermal transmittance obtained from a 1-D calculation for part k of the room or building;
A_k	is the area over which the value U_k applies;
N_n	is the total number of 3-D parts;
N_m	is the total number of 2-D parts;
N_k	is the total number of 1-D parts.

NOTE In Formula (8), ΣA_k is less than the total surface area of the envelope because some of the surface area is included in the 2-D and 3-D terms.

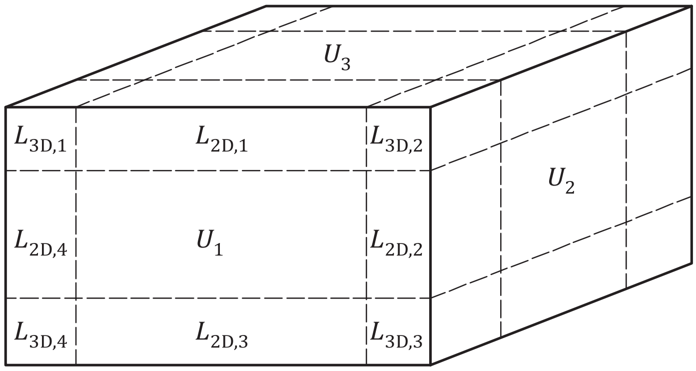


Figure 14 — Building envelope partitioned into 3-D, 2-D and 1-D geometrical models

10.3 More than two boundary temperatures

The heat flow rate, $\Phi_{i,j}$, from environment i to a thermally connected environment j is given by Formula (9):

$$\Phi_{i,j} = L_{3D,i,j} \cdot \left(\theta_i - \theta_j\right) \tag{9}$$

The total heat flow rate from a room or building can be calculated using the principles as stated in Clause 5. The heat flow rate to/from a room at temperature θ_i can be calculated from Formula (10):

$$\Phi = \sum_j \left[L_{3D,i,j} \cdot \left(\theta_i - \theta_j\right)\right] \tag{10}$$

where

$L_{3D,i,j}$ are the coupling coefficients between the room and adjacent rooms or external environments;

θ_j are the temperatures of adjacent rooms or external environments.

The total heat flow rate to/from a building can be calculated from Formula (11):

$$\Phi = \sum_i \sum_j \left[L_{3D,i,j} \cdot \left(\theta_i - \theta_j\right)\right] \tag{11}$$

where

θ_i are the temperatures of internal rooms;

θ_j are the temperatures of external environments;

$L_{3D,i,j}$ are the corresponding coupling coefficients.

NOTE E.1 provides a method to calculate the thermal coupling coefficients.

11 Calculations using linear and point thermal transmittances from 3-D calculations

11.1 Calculation of thermal coupling coefficient

The relationship between $L_{3D,i,j}$ and thermal transmittances is given by Formula (12):

$$L_{3D,i,j} = \sum_{k=1}^{N_k} U_{k(i,j)} \cdot A_k + \sum_{m=1}^{N_m} \Psi_{m(i,j)} \cdot l_m + \sum_{n=1}^{N_n} \chi_{n(i,j)} \quad (12)$$

where

$U_{k(i,j)}$ is the thermal transmittance of part k of the room or building;

A_k is the area over which the value $U_{k(i,j)}$ applies;

$\Psi_{m(i,j)}$ is the linear thermal transmittance of part m of the room or building;

l_m is the length over which the value $\Psi_{m(i,j)}$ applies;

$\chi_{n(i,j)}$ is the point thermal transmittance of part n of the room or building;

N_k is the number of thermal transmittances;

N_m is the number of linear thermal transmittances;

N_n is the number of point thermal transmittances.

NOTE 1 In Formula (12), ΣA_k is equal to the total surface area of the envelope.

NOTE 2 $L_{3D,i,j}$ is equivalent to the heat transfer coefficient, H, used in other standards.

11.2 Calculation of linear and point thermal transmittances

Ψ values are determined from Formula (13):

$$\Psi = L_{2D} - \sum_{j=1}^{N_j} U_j \cdot l_j \quad (13)$$

where

L_{2D} is the thermal coupling coefficient obtained from a 2-D calculation of the component separating the two environments being considered;

U_j is the thermal transmittance of the 1-D component, j, separating the two environments being considered;

l_j is the length over which the value U_j applies.

χ values are determined from Formula (14):

$$\chi = L_{3D} - \sum_{i=1}^{N_i} U_i \cdot A_i - \sum_{j=1}^{N_j} \Psi_j \cdot l_j \quad (14)$$

where

L_{3D} is the thermal coupling coefficient obtained from a 3-D calculation of the 3-D component separating the two environments being considered;

U_i is the thermal transmittance of the 1-D component i separating the two environments being considered;

A_i is the area over which the value U_i applies;

Ψ_j are linear thermal transmittances calculated using Formula (18);

l_j is the length over which the value Ψ_j applies;

N_j is the number of 2-D components;

N_i is the number of 1-D components.

When determining Ψ and χ values, it is necessary to state which dimensions (e.g. internal or external) are being used, because for several types of thermal bridges, the Ψ and χ values depend on this choice.

NOTE Annex D provides examples of the calculation of Ψ and χ values.

12 Determination of thermal coupling coefficient, heat flow rate and linear thermal transmittance from 2-D calculations

12.1 Two boundary temperatures

The heat flow rate per metre length, Φ_l, of the linear thermal bridge from the internal environment, designated by the subscript “int”, to the external environment, designated by the subscript “e”, is given by Formula (15):

$$\Phi_l = L_{2D} \cdot (\theta_{int} - \theta_e) \tag{15}$$

where L_{2D} is the thermal coupling coefficient obtained from a 2-D calculation of the component separating the two environments being considered.

12.2 More than two boundary temperatures

The heat flow rate, $\Phi_{i,j}$, from environment i to a thermally connected environment j is given by Formula (16):

$$\Phi_{i,j} = L_{2D,i,j} \cdot \left(\theta_i - \theta_j\right) \tag{16}$$

For more than two environments with different temperatures (e.g. different internal temperatures or different external temperatures), the total heat flow rate Φ to/from the room or the building can be calculated from Formula (17):

$$\Phi = \sum_{i<j} \left[L_{2D,i,j} \cdot \left(\theta_i - \theta_j\right)\right] \tag{17}$$

where $L_{2D,i,j}$ are the coupling coefficients between each pair of environments.

12.3 Determination of the linear thermal transmittance

The linear thermal transmittance considered of the linear thermal bridge separating the two environments being, Ψ, is given by Formula (18):

$$\Psi = L_{2D} - \sum_{j=1}^{N_j} U_j \cdot l_j \tag{18}$$

where

U_j is the thermal transmittance of the 1-D component j separating the two environments being considered;

l_j is the length within the 2-D geometrical model over which the value U_j applies;

N_j is the number of 1-D components.

When determining the linear thermal transmittance, it is necessary to state which dimensions (e.g. internal or external) are being used, because for several types of thermal bridges, the value of the linear thermal transmittance depends on this choice.

12.4 Determination of the linear thermal transmittance for wall/floor junctions

12.4.1 All cases

Numerical calculations using a two-dimensional geometrical model can be used to determine values of linear thermal transmittance for wall/floor junctions.

Model the full detail, including half the floor width or 4 m (whichever is smaller) and a section of the wall to height h_W, and calculate L_{2D} as the heat flow rate per temperature difference and per perimeter length. h_W shall be the minimum distance from the junction to a cut-off plane in accordance with the criteria in 7.2.3 and h_f shall be the height of the top of the floor slab above ground level (see Figure 15). The dimensions of the model outside the building and below ground extend to 2,5 times the floor width or 20 m (whichever is smaller). See also 7.2.5.

If the calculation is done using a 4 m floor width (i.e. B = 8 m), the result can be used for any floor of greater size (B > 8 m).

The calculation is then continued using Option A (see 12.4.2) or Option B (see 12.4.3).

A template for specifying the choice between these options is given in Table A.4, with an informative default list in Table B.4.

12.4.2 Option A

12.4.2.1 Inside floor level equal to or higher than outside ground level

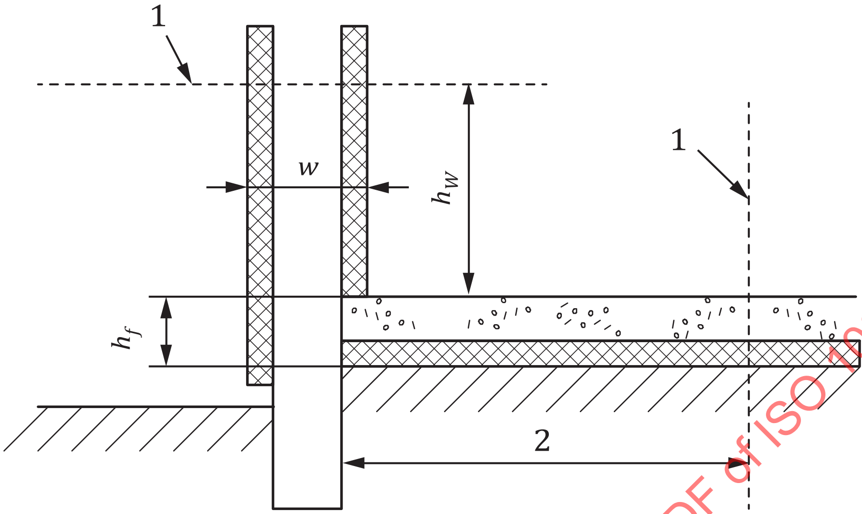
L_{2D} is obtained by numerical calculation of whole detail (including soil, edge insulation, as applicable). U_W is calculated using ISO 6946, while U_g is calculated using the simplified procedure in ISO 13370, including any all-over insulation of the floor slab and where applicable correction for edge insulation (see Figure 15).

Calculate Ψ_g by Formula (19) using internal dimensions and by Formula (20) using external dimensions:

$$\Psi_g = L_{2D} - h_W \cdot U_W - 0{,}5 \times B \cdot U_g \tag{19}$$

$$\Psi_g = L_{2D} - \left(h_W + h_f\right) \cdot U_W - \left(0{,}5 \times B + w\right) \cdot U_g \tag{20}$$

where U_W is the thermal transmittance of the wall above ground, as modelled in the numerical calculation.



Key

1 adiabatic boundary

2 0,5 × *B* or 4 m

h_f height of the top of the floor slab above ground level

h_W minimum distance from junction to cut-off plane (see 7.2.3)

w width of the wall above ground

NOTE The dimensions of the model extend to 0,5 × *B* inside the building and to 2,5 × *B* outside the building and below ground.

Figure 15 — Model for calculation of linear thermal transmittance of wall/floor junction (inside floor level equal to or higher than outside ground level)

12.4.2.2 Inside floor level below outside ground level

L_{2D} is obtained by numerical calculation of whole detail (including soil, basement and edge insulation, as applicable). U_W is calculated using ISO 6946, while U_g and $U_{w,b}$ are calculated using the simplified procedure in ISO 13370 for a heated basement including any all-over insulation of the floor slab and transmission through basement wall and, where applicable, allowance for basement depth and correction for to edge insulation (see Figure 16).

Calculate Ψ_g by Formula (21) using internal dimensions and by Formula (22) using external dimensions:

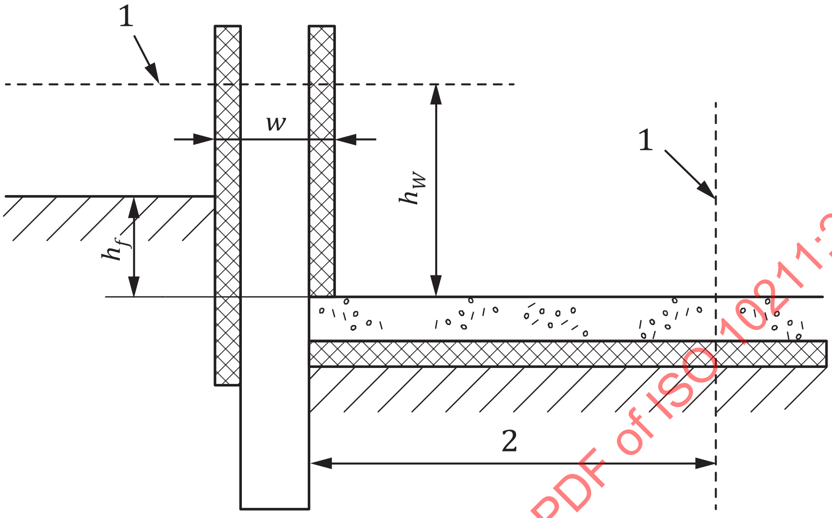
$$\Psi_g = L_{2D} - \left(h_W - h_f\right) \cdot U_W - h_f \cdot U_{w,b} - 0{,}5 \times B\, U_g \tag{21}$$

$$\Psi_g = L_{2D} - \left(h_W - h_f\right) \cdot U_W - h_f \cdot U_{w,b} - \left(0{,}5 \times B + w\right) \cdot U_g \tag{22}$$

where

U_W is the thermal transmittance of the wall above ground, as modelled in the numerical calculation;

$U_{w,b}$ is the thermal transmittance of basement wall, as calculated in ISO 13370.



Key

1 adiabatic boundary

2 0,5 × *B* or 4 m

h_f height of the top of the floor slab below ground level (basement wall)

h_W minimum distance from junction to cut-off plane (see 7.2.3)

w wall thickness

NOTE The dimensions of the model extend to 0,5 × *B* inside the building and to 2,5 × *B* outside the building and below ground.

Figure 16 — Model for calculation of linear thermal transmittance of wall/floor junction (inside floor level below outside ground level)

12.4.3 Option B

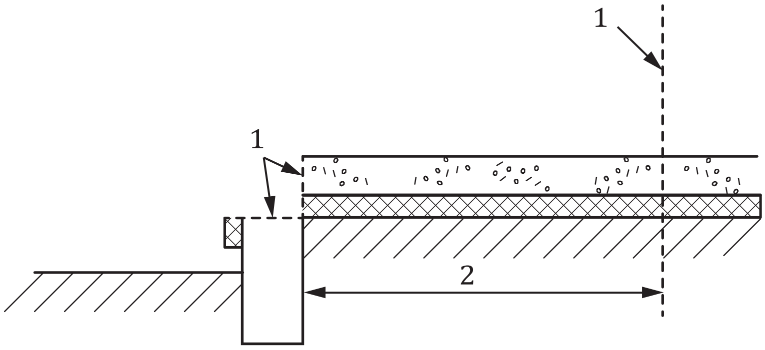
12.4.3.1 Inside floor level equal to or higher than outside ground level

Remove the wall down to the level of the underside of the floor slab (see Figure 17). Use adiabatic boundaries where the wall was previously in contact with the floor slab or the ground. Obtain $L_{2D,a}$ by a second numerical calculation on the revised detail.

Both L_{2D} and $L_{2D,a}$ are obtained by numerical calculation according to the procedure described in 12.4. U_W is calculated using ISO 6946.

Then,

$$\Psi_g = L_{2D} - h_W \cdot U_W - L_{2D,a} \tag{23}$$



Key

1 adiabatic boundary

2 0,5 × *B* or 4 m

Figure 17 — Model for second numerical calculation for Option B (inside floor level equal to or higher than outside ground level)

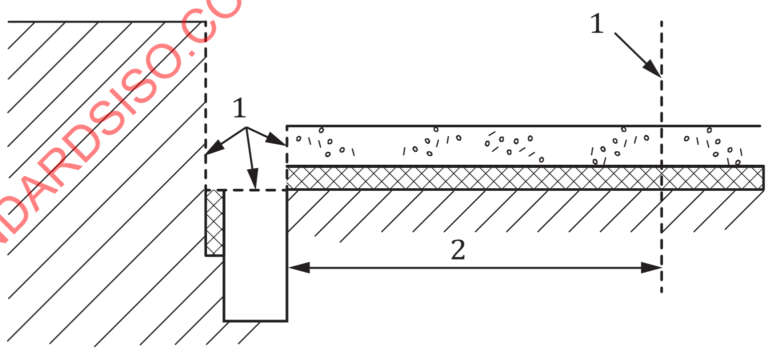
12.4.3.2 Inside floor level below outside ground level

Replace all material below ground with soil (but retaining any all-over floor insulation) and remove the wall down to the level of the underside of the floor slab (see Figure 18). Use adiabatic boundaries where the wall was previously in contact with the floor slab or the ground. Obtain $L_{2D,a}$ by a second numerical calculation on the revised detail.

Both L_{2D} and $L_{2D,a}$ are obtained by numerical calculation according to the procedure described in 12.4. U_W is calculated using ISO 6946.

Then

$$\Psi_g = L_{2D} - (h_W - h_f) \cdot U_W - L_{2D,a} \quad (24)$$



Key

1 adiabatic boundary

2 0,5 × *B* or 4 m

Figure 18 — Model for second numerical calculation for Option B (inside floor level below outside ground level)

12.5 Determination of the external periodic heat transfer coefficient for ground floors

The geometrical model of 12.4 can be used with a time-dependent numerical calculation method to determine both Ψ_g and the external periodic heat transfer coefficient, H_{pe}. The size of the time-steps should be such as to ensure a stable calculation. Determine the mean total heat flow through the internal surfaces in W/m for each month of the year. The calculation is continued until the heat flow through the internal surfaces for the month of December of the last year differs by less than 1 % from the heat flow in December for the previous year. This can normally be obtained by calculating at least 10 years.

The internal temperature is kept at a constant value, $\bar{\theta}_i$, and the external temperature, at time t, in °C, $\theta_e(t)$, is represented by Formula (25):

$$\theta_e\left(t\right) = \bar{\theta}_e - \hat{\theta}_e \cdot \cos\left(2\pi \cdot \frac{t-\tau}{12}\right) \qquad (25)$$

where

$\bar{\theta}_e$ is the annual average external temperature, in °C;

$\hat{\theta}_e$ is the amplitude of variations in monthly mean external temperature, in K;

t is the time, expressed in months (t = 0 at the beginning of January);

τ is the time, expressed in months, at which the minimum external temperature occurs.

For further information, including properties of the ground, see ISO 13370.

For each month, obtain the heat flow, q_m, in addition to that accounted for by U_W and U_g, as given in Formula (26):

$$q_m = q_{c,m} - h_W \cdot U_W \cdot \left(\bar{\theta}_{int} - \theta_{e,m}\right) - 0,5 \times B \cdot U_g \cdot \left(\bar{\theta}_{int} - \bar{\theta}_e\right) \qquad (26)$$

where $q_{c,m}$ is the mean heat flow through the internal surfaces in month m, as obtained from the numerical results. Then, as given in Formula (27):

$$\Psi_g = \frac{\sum_{m=1}^{12} q_m}{12 \times \left(\bar{\theta}_{int} - \bar{\theta}_e\right)} \qquad (27)$$

and Formula (28):

$$H_{pe} = P \cdot \left(\frac{q_{max} - q_{min}}{2 \times \hat{\theta}_e}\right) \qquad (28)$$

where

P is the exposed perimeter of the floor;

q_{max} is the maximum value of q_m;

q_{min} is the minimum value of q_m.

NOTE H_{pe} calculated using Formula (28) includes Ψ_g.

13 Determination of the temperature at the internal surface

13.1 Determination of the temperature at the internal surface from 3-D calculations

13.1.1 Two boundary temperatures

If there are only two environments involved and the subsoil is not a part of the geometrical model, the surface temperatures can be expressed in a dimensionless form in accordance with Formula (29):

$$f_{\text{Rsi}}\left(x,y,z\right)=\frac{\theta_{\text{si}}\left(x,y,z\right)-\theta_{\text{e}}}{\theta_{\text{int}}-\theta_{\text{e}}} \quad (29)$$

where

$f_{\text{Rsi}}(x,y,z)$ is the temperature factor at the internal surface at point (x,y,z);

$\theta_{\text{si}}(x,y,z)$ is the temperature at the internal surface at point (x,y,z);

θ_{int} is the internal temperature;

θ_{e} is the external temperature.

The temperature factor shall be calculated with an error of less than 0,005.

13.1.2 More than two boundary temperatures

If there are more than two boundary temperatures, the temperature weighting factor, g, shall be used. The temperature weighting factors provide the means to calculate the temperature at any location at the inner surface with coordinates (x,y,z) as a linear function of any set of boundary temperatures.

NOTE 1 At least three boundary temperatures are involved if the geometrical model includes internal environments with different temperatures.

Using the temperature weighting factors, the surface temperature at location (x,y,z) in environment j is given by Formula (30):

$$\theta_j\left(x,y,z\right)=g_{j,1}\left(x,y,z\right)\cdot\theta_1+g_{j,2}\left(x,y,z\right)\cdot\theta_2+\ldots\ldots+g_{j,n}\left(x,y,z\right)\cdot\theta_n \quad (30)$$

with Formula (31):

$$g_{j,1}\left(x,y,z\right)+g_{j,2}\left(x,y,z\right)+\ldots\ldots+g_{j,n}\left(x,y,z\right)=1 \quad (31)$$

NOTE 2 E.3 provides a method for calculating the weighting factors.

Calculate the internal surface temperature, θ_{si}, at the location of interest by inserting the calculated values of $g_{j,i}$ and the actual boundary temperatures, θ_i, in Formula (30).

NOTE 3 The location of interest is normally the point with the lowest internal surface temperature. This location can vary if the boundary temperatures are changed.

13.2 Determination of the temperature at the internal surface from 2-D calculations

13.2.1 Two boundary temperatures

When there are only two environments involved, the surface temperatures can be expressed in a dimensionless form in accordance with Formula (32):

$$f_{\mathrm{Rsi}}(x,y)=\frac{\theta_{\mathrm{si}}(x,y)-\theta_{\mathrm{e}}}{\theta_{\mathrm{int}}-\theta_{\mathrm{e}}} \tag{32}$$

where

$f_{\mathrm{Rsi}}(x,y)$ is the temperature factor for the internal surface at point (x,y);

$\theta_{\mathrm{si}}(x,y)$ is the temperature for the internal surface at point (x,y);

θ_{int} is the internal temperature;

θ_{e} is the external temperature.

The temperature factor shall be calculated with an error of less than 0,005.

13.2.2 Three boundary temperatures

If there are three boundary temperatures involved, temperature weighting factors, *g*, shall be used. Temperature weighting factors provide the means to calculate the temperature at any location of the internal surface with coordinates (x,y) as a linear function of any set of boundary temperatures.

The surface temperatures at the location (x,y) in environment *j* are given by Formula (33):

$$\theta_j(x,y)=g_{j,1}(x,y)\cdot\theta_1+g_{j,2}(x,y)\cdot\theta_2+g_{j,3}(x,y)\cdot\theta_3 \tag{33}$$

with Formula (34):

$$g_{j,1}(x,y)+g_{j,2}(x,y)+g_{j,3}(x,y)=1 \tag{34}$$

NOTE The weighting factors at the location of interest can be calculated in accordance with Annex E. The location of interest is normally the point with the lowest internal surface temperature. This location can vary if the boundary temperatures are changed.

14 Report

14.1 Input data

The report of the calculation shall contain the following information:

a) description of structure:

— building plans including dimensions and materials;

— for a completed building, any known alterations to the construction and/or physical measurements and details from inspection;

— other relevant remarks;

b) description of the geometrical model:

— 2-D or 3-D geometrical model with dimensions;

— input data showing the location of the construction planes and any auxiliary planes, together with the thermal conductivities of the various materials;

— the applied boundary temperatures;

— a calculation of the boundary temperature in an adjacent area, when appropriate;

— the surface resistances and the areas to which they apply;

— any dimensional adjustments in accordance with 7.3.2;

— any quasi-homogeneous layers and the thermal conductivities calculated in accordance with 7.3.3;

— any non-standard values used with justification of the deviation from standard values (see 8.1).

14.2 Output data

14.2.1 General

The following calculation results shall be reported as values that are independent of the boundary temperatures:

— thermal coupling coefficient L_{3D} or L_{2D} between adjacent rooms involved in heat transfer through the building components;

NOTE 1 An example is given in Table E.2.

— if appropriate, the linear thermal transmittance, Ψ, of the linear thermal bridge, stating whether internal or external dimensions were used;

— temperature factor, f_{Rsi}, for the points of lowest surface temperatures in each room involved (including the location of these points); if more than two boundary temperatures are used, the temperature weighting factors shall be reported.

NOTE 2 An example of how to report temperature weighting factors is given in Table E.4.

All output values shall be given to at least three significant figures.

14.2.2 Calculation of the heat transmission using the thermal coupling coefficient

The heat transmission from environment i to environment j is given by Formula (10) if there are more than two boundary temperatures, by Formula (9) if there are two boundary temperatures, or by Formula (15) for a 2-D geometrical model.

14.2.3 Calculation of the surface temperatures using weighting factors

The lowest internal surface temperature exposed to room j is given by Formula (30) for a 3-D geometrical model or by Formula (33) for a 2-D geometrical model.

14.2.4 Additional output data

For a specific set of boundary temperatures, the following additional values shall be presented:

— heat flow rates, in watts per metre (for 2-D cases) or in watts (for 3-D cases), for each pair of rooms of interest;

— minimum surface temperatures, in degrees Celsius, and the location of the points with minimum surface temperature in each room of interest.

14.2.5 Estimate of error

Numerical procedures give approximate solutions which converge to analytical solutions, if one exists. In order to evaluate the reliability of the results, the residual error should be estimated, as described below.

— In order to estimate errors due to insufficient numbers of cells, additional calculation(s) shall be made in accordance with C.2. The difference in results for both calculations shall be stated.

— In order to estimate errors arising in the numerical solution of the equation system, the sum of heat flows (positive and negative) over all boundaries of the building component divided by the total heat flow shall be given.

NOTE C.2 specifies that this quotient is to be less than 0,000 1.

A template for specifying the maximum permitted error is given in Table A.5, with an informative default in Table B.5.

Annex A
(normative)

Input and method selection data sheet — Template

A.1 General

The template in Annex A of this document shall be used to specify the choices between methods, the required input data and references to other documents.

NOTE 1 Following this template is not enough to guarantee consistency of data.

NOTE 2 Informative default choices are provided in Annex B. Alternative values and choices can be imposed by national/regional regulations. If the default values and choices of Annex B are not adopted because of the national/regional regulations, policies or national traditions, it is expected that:

— national or regional authorities prepare data sheets containing the national or regional values and choices, in line with the template in Annex A; or

— by default, the national standards body will add or include a national annex (Annex NA) to this document, in line with the template in Annex A, giving national or regional values and choices in accordance with their legal documents.

NOTE 3 The template in Annex A is applicable to different applications (e.g., the design of a new building, certification of a new building, renovation of an existing building and certification of an existing building) and for different types of buildings (e.g., small or simple buildings and large or complex buildings). A distinction in values and choices for different applications or building types could be made:

— by adding columns or rows (one for each application), if the template allows;

— by including more than one version of a table (one for each application), numbered consecutively as a, b, c, ... For example: Table NA.3a, Table NA.3b;

— by developing different national/regional data sheets for the same standard. In case of a national annex to the standard these will be consecutively numbered (Annex NA, Annex NB, Annex NC, ...).

NOTE 4 In the section "Introduction" of a national/regional data sheet information can be added, for example about the applicable national/regional regulations.

NOTE 5 For certain input values to be acquired by the user, a data sheet following the template of Annex A, could contain a reference to national procedures for assessing the needed input data. For instance, reference to a national assessment protocol comprising decision trees, tables and pre-calculations.

The shaded fields in the tables are part of the template and consequently not open for input.

A.2 References

The references, identified by the module code number, are given in Table A.1.

Table A.1 — References

Reference	Reference document[a]	
	Number	Title
Mx-y[b]	...	...
	...	...

[a] If a reference comprises more than one document, the references may be differentiated.

[b] In this document, there are no choices in references to other EPB standards. The table is kept to maintain uniformity between all EPB standards.

A.3 Selection of methods

In this document, there is no need to specify choices in methods. A.3 is kept to maintain uniformity between all EPB standards.

A.4 Input data and choices

Table A.2 — Restrictions on simplifications of the geometrical model (see 7.3.1)

Item	Restrictions
Restrictions on simplification of the geometrical model	Provide list of restrictions

Table A.3 — Default thermal conductivity values (see 8.2)

Material[a]	Thermal conductivity λ W/(m·K)

[a] Rows may be deleted or added and materials may be further specified or grouped.

Table A.4 — Basis of calculation for wall/floor junctions (see 12.4.1)

Item	Choice
Option A or B as defined in 12.4	A or B

Table A.5 — Requirement to estimate maximum error of numerical method (see 14.2.5)

Item	Choice
Maximum error on numerical method?	Yes/No
If Yes, maximum value of the error	.... %

Annex B
(informative)

Input and method selection data sheet — Default choices

B.1 General

The template in Annex A of this document shall be used to specify the choices between methods, the required input data and references to other documents.

NOTE 1 Following this template is not enough to guarantee consistency of data.

NOTE 2 Informative default choices are provided in Annex B. Alternative values and choices can be imposed by national/regional regulations. If the default values and choices of Annex B are not adopted because of the national/regional regulations, policies or national traditions, it is expected that:

— national or regional authorities prepare data sheets containing the national or regional values and choices, in line with the template in Annex A; or

— by default, the national standards body will add or include a national annex (Annex NA) to this document, in line with the template in Annex A, giving national or regional values and choices in accordance with their legal documents.

NOTE 3 The template in Annex A is applicable to different applications (e.g., the design of a new building, certification of a new building, renovation of an existing building and certification of an existing building) and for different types of buildings (e.g., small or simple buildings and large or complex buildings). A distinction in values and choices for different applications or building types could be made:

— by adding columns or rows (one for each application), if the template allows;

— by including more than one version of a table (one for each application), numbered consecutively as a, b, c, ... For example: Table NA.3a, Table NA.3b;

— by developing different national/regional data sheets for the same standard. In case of a national annex to the standard these will be consecutively numbered (Annex NA, Annex NB, Annex NC, ...).

NOTE 4 In the section "Introduction" of a national/regional data sheet information can be added, for example about the applicable national/regional regulations.

NOTE 5 For certain input values to be acquired by the user, a data sheet following the template of Annex A, could contain a reference to national procedures for assessing the needed input data. For instance, reference to a national assessment protocol comprising decision trees, tables and pre-calculations.

The shaded fields in the tables are part of the template and consequently not open for input.

B.2 References

The references, identified by the module code number, are given in Table B.1.

Table B.1 — References

Reference	Reference document[a]	
	Number	Title
Mx-y[b]	...	...
	...	...

[a] If a reference comprises more than one document, the references may be differentiated.

[b] In this document, there are no choices in references to other EPB standards. The table is kept to maintain uniformity between all EPB standards.

B.3 Selection of methods

In this document, there is no need to specify choices in methods. B.3 is kept to maintain uniformity between all EPB standards.

B.4 Input data and choices

Table B.2 — Restrictions on simplifications of the geometrical model (see 7.3.1)

Item	Restrictions
Restrictions on simplification of the geometrical model	As in 7.3

Table B.3 — Default thermal conductivity values (see 8.2)

Material[a]	Thermal conductivity λ W/(m·K)
Materials with properties in ISO or EN product standard or listed in ISO 10456	Values according to product standard if available, otherwise from ISO 10456

[a] Rows may be deleted or added and materials may be further specified or grouped.

Table B.4 — Basis of calculation for wall/floor junctions (see 12.4.1)

Item	Choice
Option A or B as defined in 12.4	B

Table B.5 — Requirement to estimate maximum error of numerical method (see 14.2.5)

Item	Choice
Maximum error on numerical method?	No
If Yes, maximum value of the error	—

Annex C
(normative)

Validation of calculation methods

C.1 Test reference cases

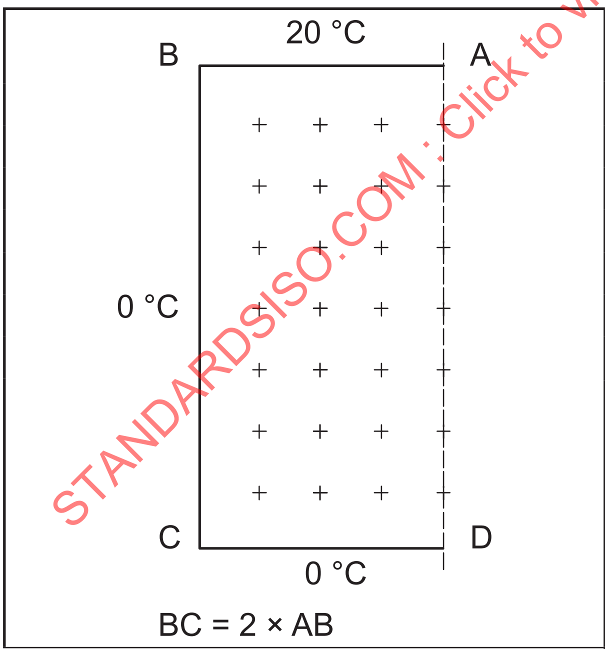
C.1.1 General

In order to be classified as a three-dimensional steady-state high precision method, a calculation method shall give results corresponding to those of the test reference cases 1, 2, 3, and 4, represented respectively in Figure C.1, Figure C.2, Figure C.3 and Figure C.4.

In order to be classified as a two-dimensional steady-state high precision method, it shall give results corresponding to those of the test reference cases 1 and 2, represented respectively in Figure C.1 and Figure C.2.

C.1.2 Case 1

The heat transfer through half a square column, with known surface temperatures, can be calculated analytically, as shown in Figure C.1. The analytical solution at 28 points of an equidistant grid is given in the same figure. The difference between the temperatures calculated by the method being validated and the temperatures listed shall not exceed 0,1 °C.



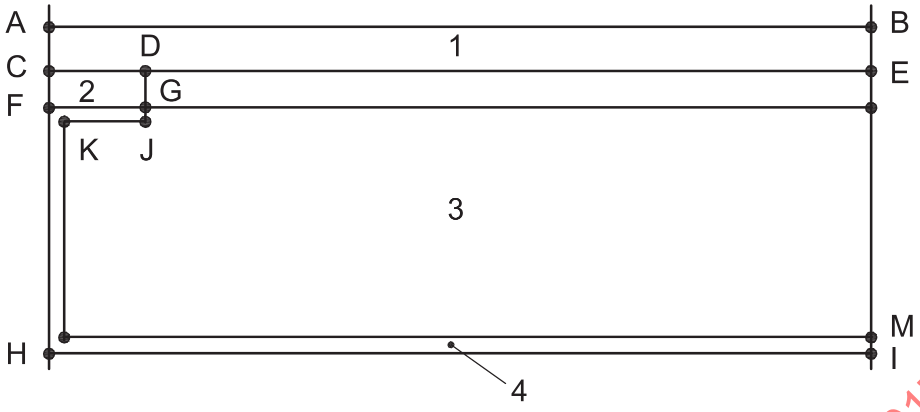
Analytical solution at grid nodes (°C)			
9,7	13,4	14,7	15,1
5,3	8,6	10,3	10,8
3,2	5,6	7,0	7,5
2,0	3,6	4,7	5,0
1,3	2,3	3,0	3,2
0,7	1,4	1,8	1,9
0,3	0,6	0,8	0,9

Figure C.1 — Test reference case 1: comparison with the analytical solution

C.1.3 Case 2

C.1.3.1 Description of the model for case 2

An example of two-dimensional heat transfer is given in Figure C.2, Table C.1 and Table C.2.



Key

1 concrete
2 wood
3 insulation
4 aluminium

Figure C.2 — Test reference case 2: two-dimensional heat transfer

Table C.1 — Description of model for case 2

Dimensions mm	**Thermal conductivity** W/(m·K)	**Boundary conditions**
AB = 500	1: 1,15	AB: 0 °C with R_{se} = 0,06 m²·K/W
AC = 6	2: 0,12	HI: 20 °C with R_{si} = 0,11 m²·K/W
CD = 15	3: 0,029	—
CF = 5	4: 230	—
EM = 40	—	—
GJ = 1,5	—	—
IM = 1,5	—	—
FG − KJ = 1,5	—	—

C.1.3.2 Numerical solution for case 2

Table C.2 — Temperature results for case 2

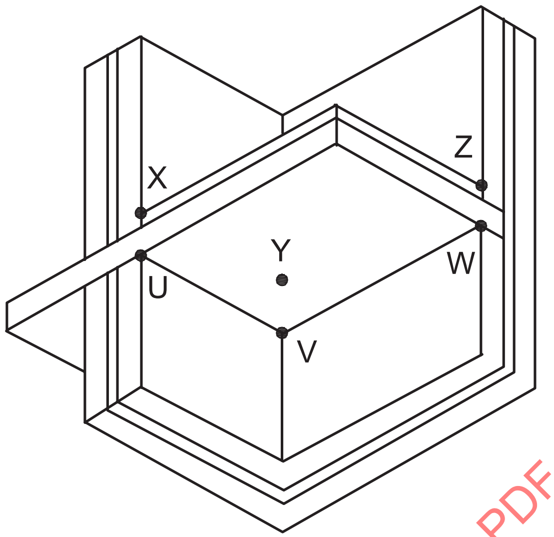
Temperatures °C		
A: 7,1		B: 0,8
C: 7,9	D: 6,3	E: 0,8
F: 16,4	G: 16,3	
H: 16,8		I: 18,3
Total heat flow rate: 9,5 W/m		

The difference between the temperatures calculated by the method being validated and the temperatures listed shall not exceed 0,1 °C. The difference between the heat flow calculated by the method being validated and the heat flow listed shall not exceed 0,1 W/m.

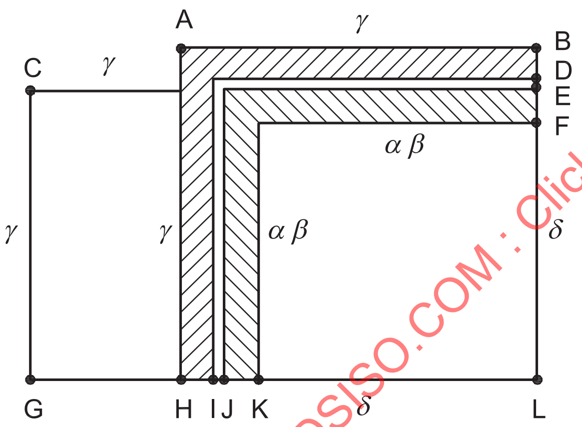
C.1.4 Case 3

C.1.4.1 Description of the model for case 3

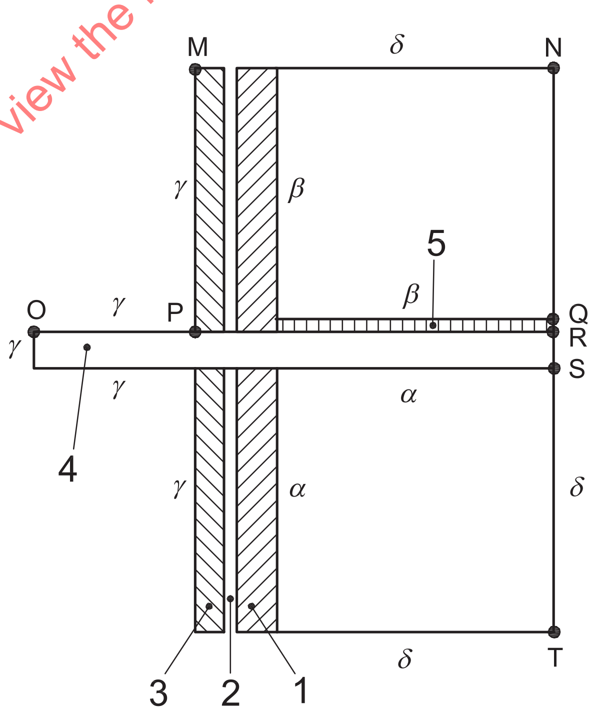
An example of three-dimensional heat transfer is given in Figure C.3, Table C.3, Table C.4 and Table C.5.



a) **Perspective view**



b) **Horizontal section**



c) **Vertical section**

NOTE Y and V are three-dimensional corners.

Figure C.3 — Test reference case 3: three-dimensional geometrical model

Table C.3 — Description of the model for case 3

Dimensions mm	Thermal conductivity W/(m·K)	Boundary conditions
AB = 1300	1: 0,7	α: 20 °C with R_{si} = 0,20 m²·K/W
BD = HI = 100	2: 0,04	β: 15 °C with R_{si} = 0,20 m²·K/W
DE = IJ = 50	3: 1,0	γ: 0 °C with R_{se} = 0,05 m²·K/W
EF = JK = 150	4: 2,5	δ: adiabatic
FL = KL = 1 000	5: 1,0	
CG = 1150		
GH = 600		
MP = ST = 1 000		
QR = 50		
RS = 150		
NQ = 950		
OP = 600		

C.1.4.2 Numerical solution for case 3: surface temperature factors

Table C.4 — Temperature results for case 3

Environment	Temperature factors		
	g_γ	g_α	g_β
γ	1,000	0,000	0,000
α	0,378	0,399	0,223
β	0,331	0,214	0,455

The lowest surface temperatures in the environments α and β are in the corners of both indoor environments:

$$\theta_{min} = g_\gamma \cdot \theta_\gamma + g_\alpha \cdot \theta_\alpha + g_\beta \cdot \theta_\beta \quad (C.1)$$

$$\theta_{\alpha,min} = 0,378 \times 0 + 0,223 \times 15 + 0,399 \times 20 = 11,32\ °C \quad (C.2)$$

$$\theta_{\beta,min} = 0,331 \times 0 + 0,455 \times 15 + 0,214 \times 20 = 11,11\ °C \quad (C.3)$$

The difference between the lowest internal surface temperature of both environments calculated by the method being validated and the temperature listed shall not exceed 0,1 °C.